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HEC-HMS Development in Support of Russian River Watershed Assessment

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PURPOSE: The objective of this technical note is to briefly describe the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) and its application to the Russian River watershed study. HEC-HMS simulates rainfall-runoff at select locations within a watershed given the physical characteristics of the watershed. It is a tool for watershed management that can be used to account for human impacts in regards to the magnitude, quantity, and timing of runoff at points of interest. The current version of HEC-HMS simulates flow and soon-to-be-released versions will also simulate sediment and water quality.

Traditionally, stream and subwatershed characterizations have been accomplished using an approach based on Digital Elevation Model (DEM) terrain analysis within a GIS. The Geo-HMS Arc View extension package was used in developing the topographic values needed to develop the initial watershed model. When the model was completed, a calibration was performed for a select sub-area within the Russian River Watershed.

HEC-HMS DESCRIPTION: HEC-HMS is designed to simulate the precipitation-runoff processes of dendritic watershed systems. Its design allows applicability in a wide range of geographic areas for solving diverse problems including large river basin water supply and flood hydrology, and small urban or natural watershed runoff. HEC-HMS is a generalized modeling system capable of representing many different watersheds. A model of the watershed is constructed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed of interest. In most cases, several model choices are available for representing each water pathway in the cycle. Each mathematical model included in the program is suitable in different environments and under different conditions. Making the correct choice requires knowledge of the watershed, the goals of the hydrologic study, and engineering judgment. The program features a completely integrated work environment including a database, data entry utilities, computation engine, and results reporting tools. A graphical user interface (GUI) allows seamless movement between the various parts of the program. The data-entry steps, program execution, and result visualization are easy within the HMS. Each of the subbasin model elements has an editor for selecting computation methods and entering the required parameter data. The user indicates method choices and specifies initial conditions and parameters using a GUI. The user is responsible for collecting and analyzing the land use and soil data necessary to compute the parameter values. The HEC-HMS model is described fully in its user manual and technical reference manual (U.S. Army Corps of Engineers Hydrologic Engineering Center (USACE HEC) 2000, 2008).

RUSSIAN RIVER WATERSHED DESCRIPTION: The Russian River Watershed encompasses 1,500 square miles of forests, agricultural lands, and urban areas within Sonoma and

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Mendocino Counties, in northern California, with 95 percent of the watershed in private ownership. The Russian River originates in central Mendocino County, approximately 15 miles north of Ukiah and flows through Sonoma County, discharging to the Pacific Ocean near the town of Jenner (Figure 1). The main channel of the Russian River is about 110 miles long and flows generally southward from its headwaters near Redwood and Potter Valleys, to Mirabel Park, where the direction of flow changes to generally westward as it crosses the Coast Range. The principal tributaries of the Russian River are East Fork, Sulphur Creek, Maacama Creek, Dry Creek, and Mark West Creek.

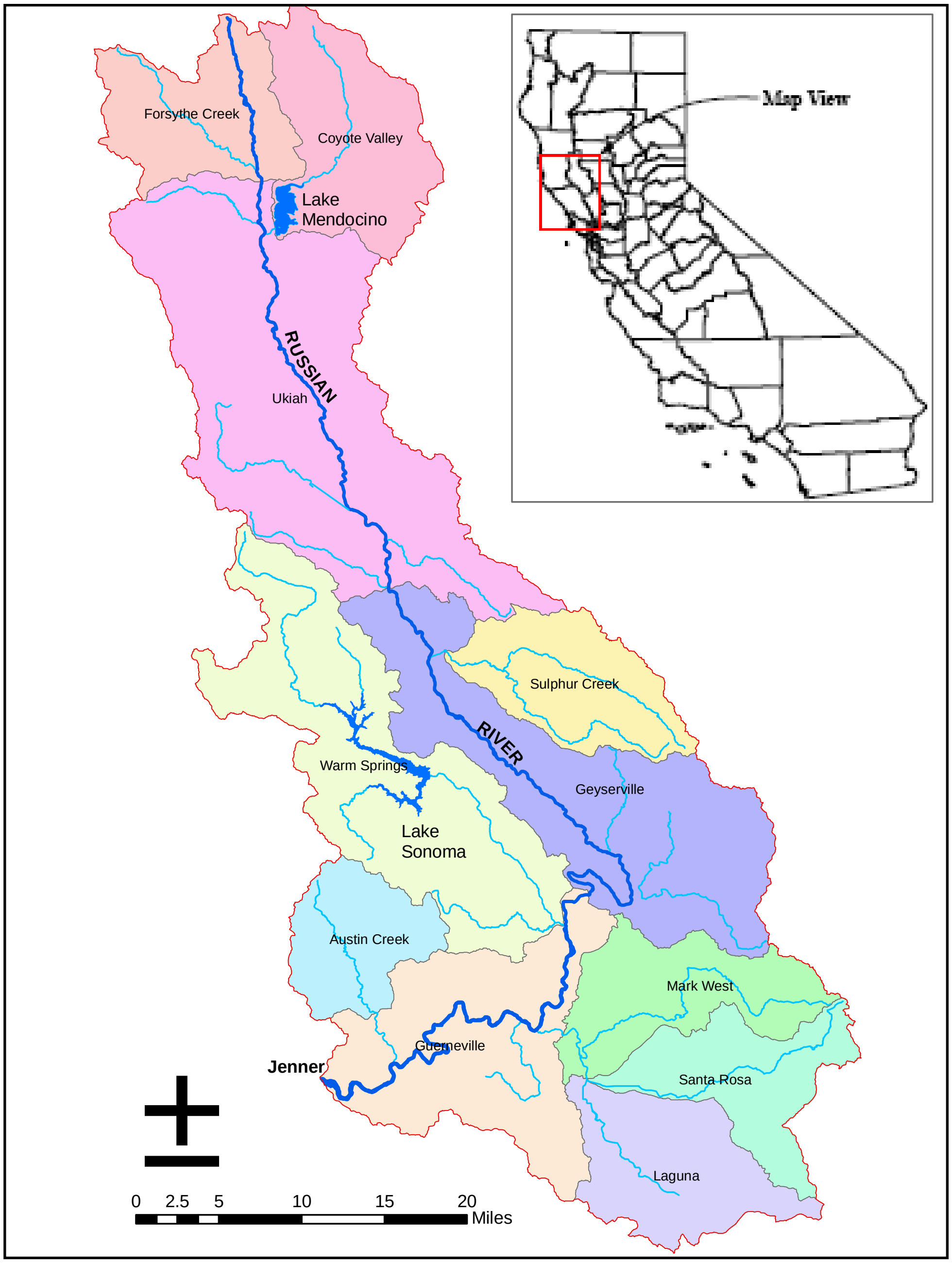


Figure 1. Russian River and Russian River watershed.

While the Russian River maintains some hydrologic characteristics typical of northern California coastal streams (high winter flows, low summer flows), the development of two relatively large storage reservoirs, Lake Sonoma and Lake Mendocino, and numerous smaller agricultural and municipal diversions, along with importation of water from the Eel River system, has altered the natural hydrology. Two major reservoirs provide the summer water supply for the Russian River watershed: Lake Mendocino on the East Fork Russian River, and Lake Sonoma on Dry Creek.

Lake Mendocino is created by Coyote Valley Dam, located on the East Fork of the Russian River, 0.8 mile upstream of the East Fork's confluence with the Russian River (see Figure 1). Coyote Valley Dam is a rolled earth embankment dam with a crest elevation of 784 ft above MSL, which is 160 ft above the original streambed. Lake Mendocino has a design capacity of 122,500 acre-ft at the spillway crest elevation of 764.8 ft above MSL, and is used to store and regulate wet season runoff as well as water imported from the Eel River. During the rainy season (November through May), natural streamflow (rather than reservoir releases) accounts for most of the flow of the Russian River. On the other hand, from June through October, most of the water in the Russian River downstream of Coyote Valley Dam and above Dry Creek is water that was released from storage at Lake Mendocino.

Lake Sonoma is created by Warm Springs Dam, located on Dry Creek, about 11 miles upstream of Dry Creek's confluence with the Russian River (see Figure 1). Warm Springs Dam is a rolled earth embankment dam with a crest elevation of 495 ft above MSL. Lake Sonoma has a design capacity of 381,000 acre-ft at the spillway crest elevation of 495 ft above MSL, and captures run-off from a drainage area of about 130 square miles. The design water supply pool capacity of Lake Sonoma is 245,000 acre-ft.

For this study, the HEC-HMS watershed model information required was found using USGS DEM, land use and soils maps, results of previous watershed studies in the area, and field investigations, such as:

- Physical characteristics of the watershed.
- Soil types and infiltration rates.
- Land use characteristics and the percent of impervious area due to development.
- Local precipitation patterns.
- Discharge records.

Watershed data included topography, land use, and soil database. The 10-m mosaic DEM of Russian River watershed was gathered. Elevations in the watershed range from 4,480 ft to sea level (Figure 2).

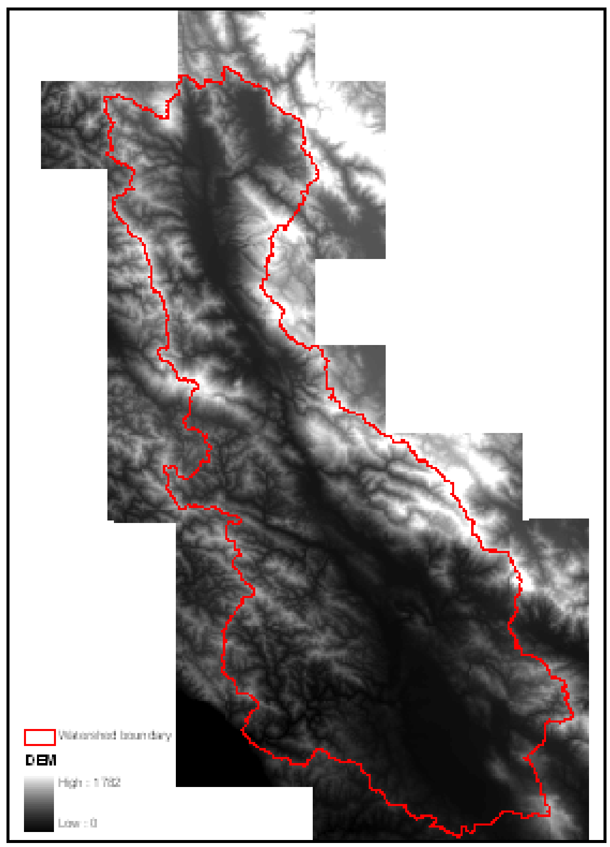
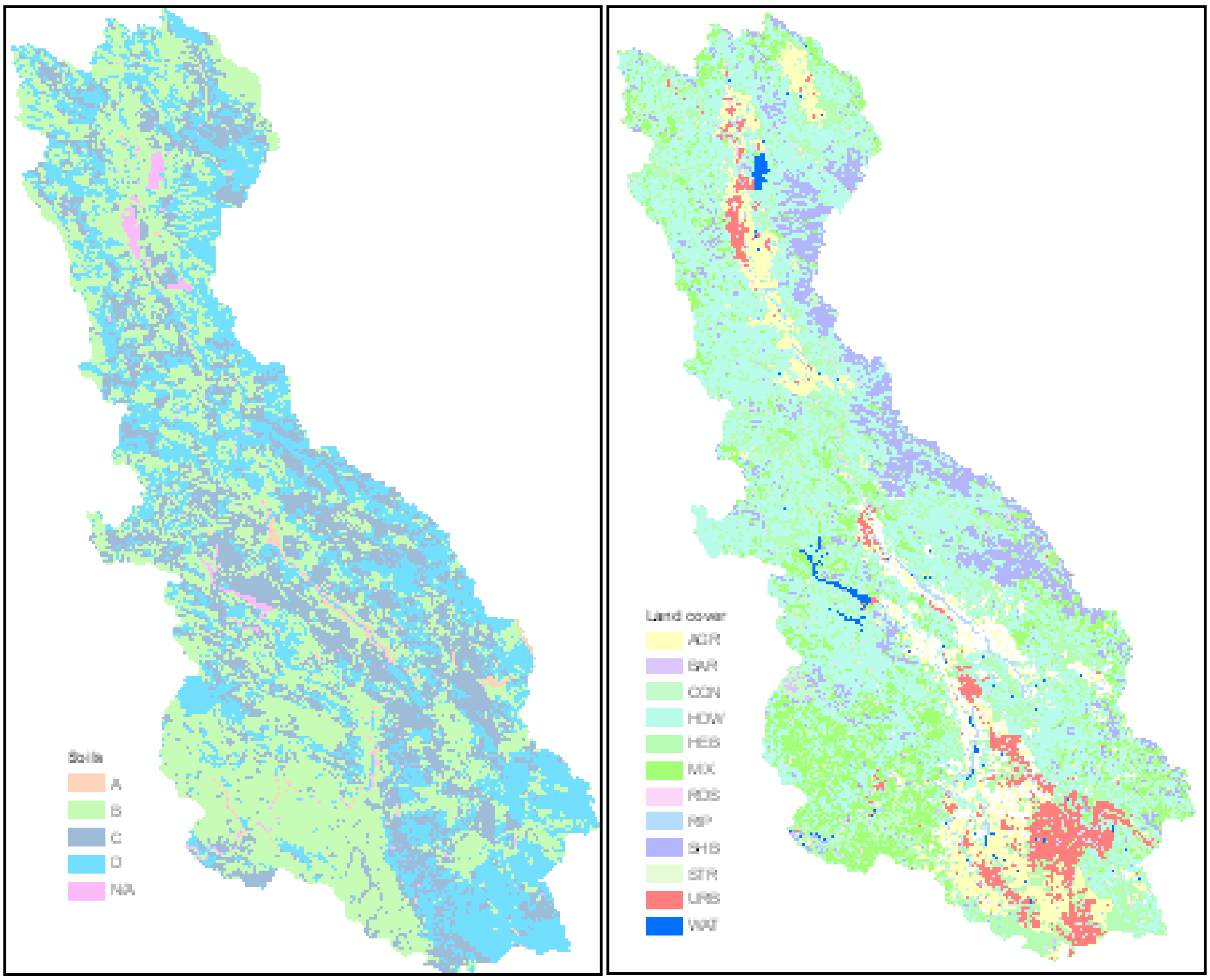


Figure 2. Russian River watershed DEM.

Soil and land cover GIS layers were provided as shown in Figure 3. Land uses in the Russian River watershed include urban and suburban development to support a burgeoning population and a growing economy, preservation of parks and open space, in addition to vineyard development and other agricultural activities. The soil data set was developed by the SSURGO and generally is the most detailed level of soil geographic data.

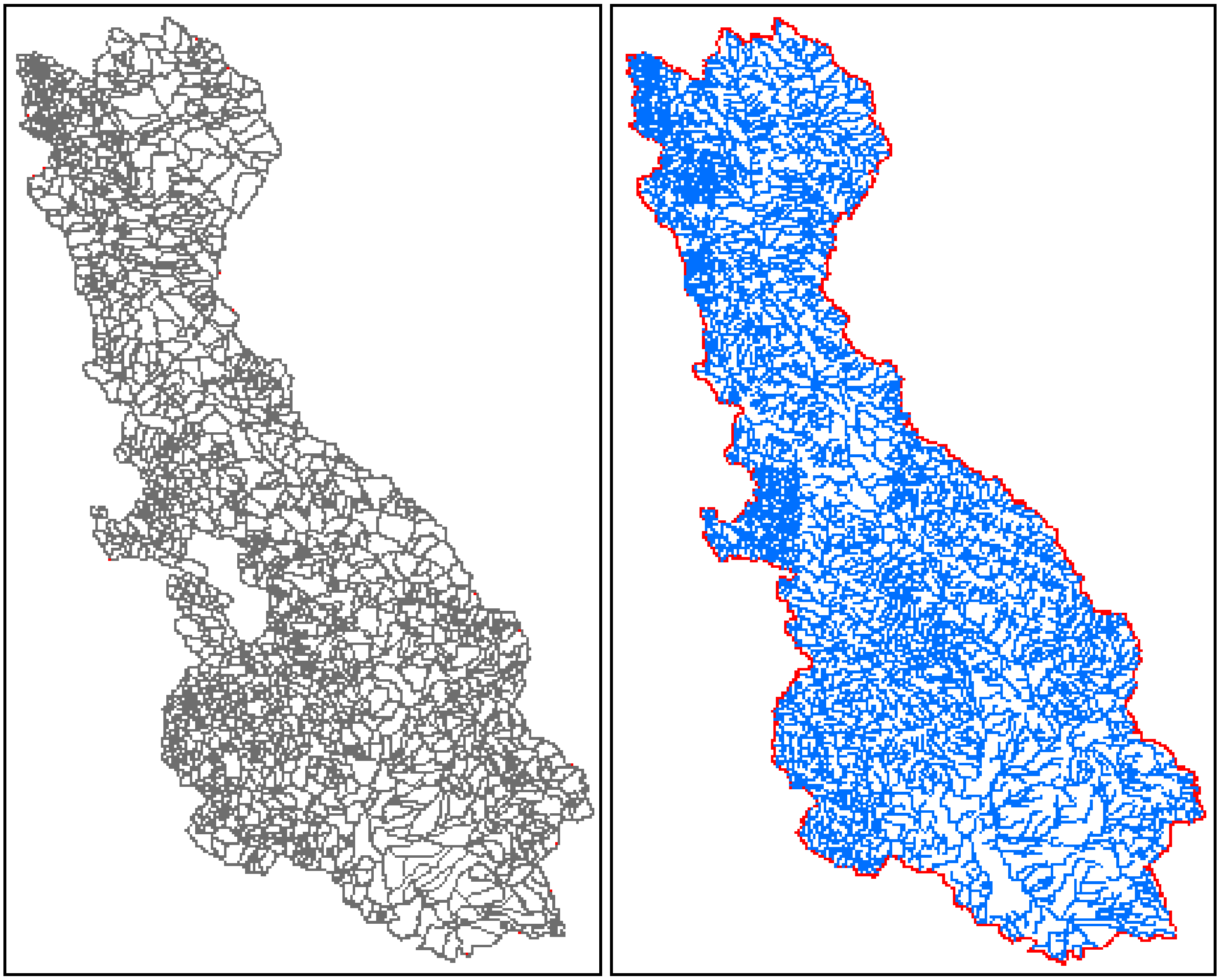


(a) (b)

Figure 3. Russian River watershed soils (a) and land use (b).

Current land use in the study area is predominantly agricultural and undeveloped lands. Agricultural land is predominantly wine-grape vineyards, with small areas of orchard and irrigated pasture. Undeveloped lands consist of grassland and woodland of varying density, primarily located in the steeper and higher elevation areas of the hills above the valleys.

The Russian River watershed has been divided into subwatershed polygons called the watershed assessment areas (WAAs) in terms of "Assessment Criteria" (Figure 4). In developing the watershed model, the existing stream and subwatershed divide data developed for stream habitat evaluation was used. Doing so requires corrections to the stream and watershed delineations computed by the GUI.



(a) (b)

Figure 4. Russian River watershed assessment areas (a) and stream networks (b).

Precipitation in the Russian River is distinctly seasonal, about 80 percent of the total occurs during 5 months, November through March. The bulk of the precipitation occurs during moderately intense general storms of several days' duration. Snow falls in moderate amounts at altitudes above 2,000 ft, but it seldom remains on the ground for more than a few days. Mean annual precipitation in the study area varies from about 30 in. in the flat valley lands north of Santa Rosa to about 50 in. in the hills west of Healdsburg. Summers are dry, with total rainfall from June through August averaging less than 0.5 in.

Current sources of water within the study area consist of the following:

- Natural stream flow in the Russian River and its tributary streams.
- Natural runoff stored in Lake Mendocino and Lake Sonoma during the wet season and released in the dry season for rediversion at downstream points.
- Groundwater within the Russian River Valley, Alexander Valley, and Dry Creek Valley.

HEC-HMS MODEL DEVELOPMENT

Model set-up: When developing a HEC-HMS model, a basin model, meteorological model, and control specifications need to be defined based on the following steps:

- Watershed subdivision.
- Watershed schematic.
- Selected model options.
- Enter gage flow data.
- Enter basin model data.
- Enter precipitation data.
- Enter model control specifications.
- Execute watershed simulation.
- View results.

The basin model includes physical representations of watersheds or basins and rivers. Hydrologic elements are connected in a dendritic network to simulate runoff processes. Available elements are: subbasin, reach, junction, reservoir, diversion, source, and sink. Meteorologic data analysis is performed by the meteorologic model and includes precipitation and evapotranspiration. The time span of a simulation is controlled by control specifications, which include a starting date and time, ending date and time, and computation time-step. Hydrologic elements are the building blocks of a basin model.

To model a watershed system, it is necessary to represent its flow elements and organize them according to proper topologic relationships. HEC-GeoHMS has been developed as a geospatial hydrology tool kit within GIS and allows users to visualize spatial information, perform spatial analysis, delineate subbasins and streams, and automatically construct watershed inputs to hydrologic models. HEC-GeoHMS provides the connection for translating GIS spatial information into HEC-HMS. Working with HEC-GeoHMS through its interfaces, it allows the user to expediently create watershed hydrologic inputs that can be used directly with the HEC-HMS. Currently, HEC-GeoHMS operates on the DEM to derive stream and subbasin delineation and prepare a number of watershed hydrologic inputs. Even though surface water features extracted from DEMs are generally accurate representations of the watershed systems, they have difficulty capturing the flow patterns in flat areas where even small inaccuracies in the elevation values can lead to major errors in the delineated streams and subbasin divides and in urban areas where the flow patterns are often modified by drainage structures. Due to the number of sub-watersheds the Russian River watershed was broken into two pieces and two separate HEC-HMS basin models were created. Figures 5a and 5b show the Upper Russian River Basin Model and the Lower Russian River Basin Model, respectively. There are 619 subbasin elements and 463 reach elements in the upper basin model, and there are 671 subbasin elements and 485 reach elements in the lower basin model. Each element represents part of the total response of the watershed to precipitation.

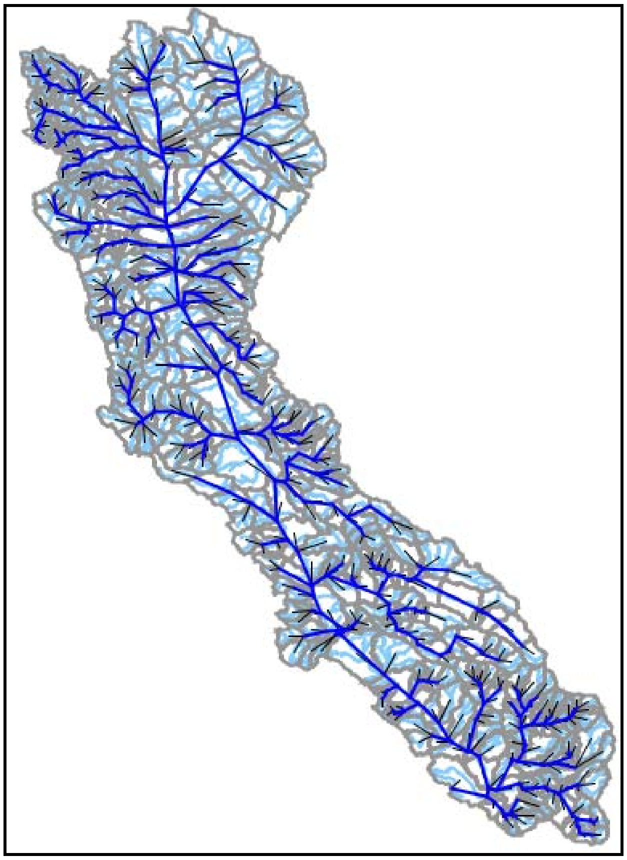


Figure 5a. Upper Russian River Basin Model.

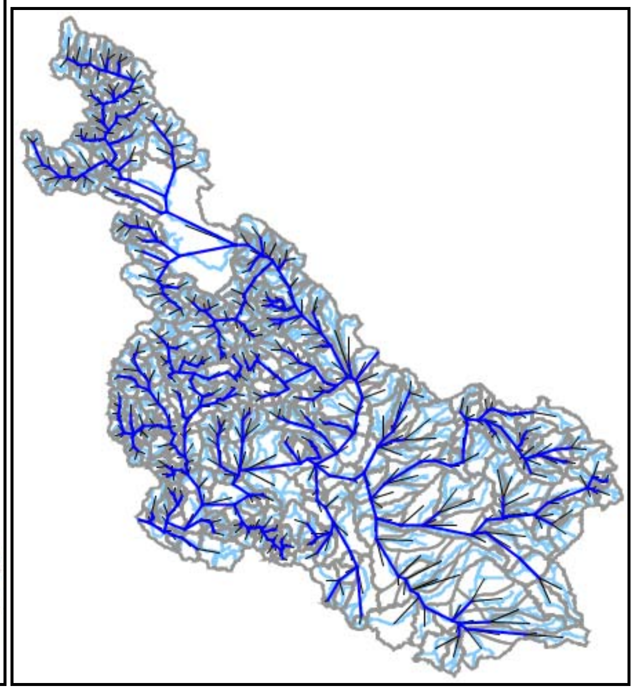


Figure 5b. Lower Russian River Basin Model.

The two reservoirs were not simulated for the event period because their discharge rating curves were not available. Forcing terms in a hydrologic model are meteorological data (i.e., precipitation). Fourteen meteorological gages over the watershed were used in this analysis. The Thiessen polygon method was used in spatially distributing the rainfall over the watershed area. Rainfall gage station locations are shown in Figure 6. Hourly rainfall data for the December 12 to 16, 2002 event were provided by U.S. Army Engineer District, San Francisco. From the data review, rainfall distribution is highly variable in both time and space. It should be noted that some date and time series data are missing.

The HEC-HMS simulation was controlled by several simulation control parameters including simulation period, the simulation time-step, and meteorological model. The model was run for the December 12 to 16, 2002 event. All input data correspond to this period.

Method selection: Once the watershed data were collected and the spatial and temporal extent had been determined, several methods were available for runoff volume, direct runoff, and channel routing.

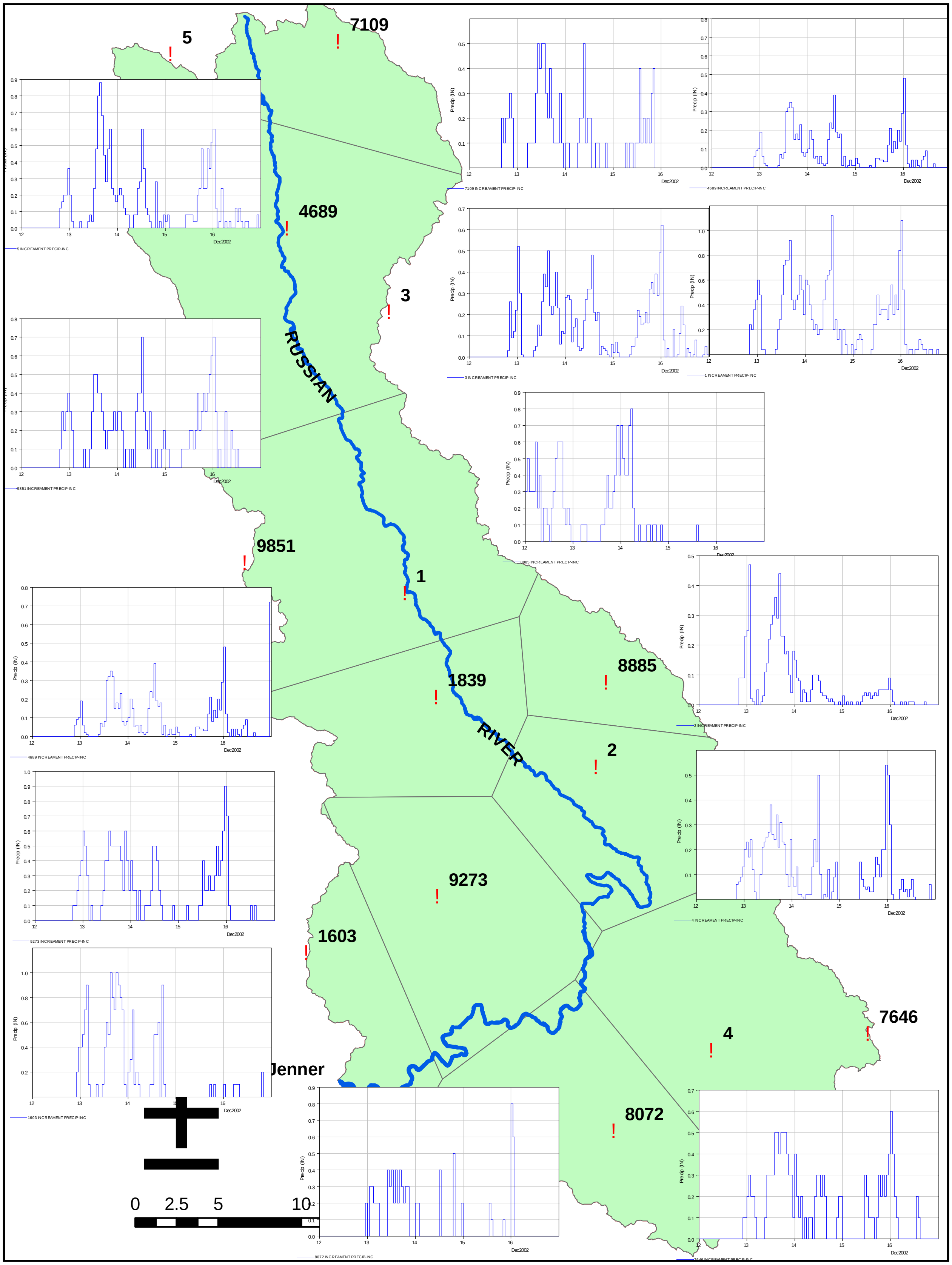


Figure 6. Rainfall gages and associated Thiessen polygons.

Infiltration. The SCS curve number method was chosen. It is widely used in the HEC-HMS modeling studies. A GIS analysis was conducted to estimate the curve number. The curve numbers were assigned according to land use and soil type. Categories in the soil type and land use maps were overlayed, and then combined, to develop subwatershed curve number maps to assign parameters to the model. Current land use in the watershed provided estimates of percent of directly impervious area as a function of land use.

Direct-runoff transform. The SCS unit hydrograph direct-runoff transform method was used. This method is widely used in the HEC-HMS watershed modeling studies. As with the loss method, a GIS analysis was conducted to estimate the lag time as a function of watershed properties.

Baseflow. Baseflow was included in the model as a calibration factor due to lack of data. Typically it is not a critical component in most mountain and urban watersheds.

Routing. The Muskingum channel routing method was used because channel geometry and roughness values were not available from this study. Channel properties such as reach length, energy slope, and channel geometry need to be measured for the channel routing methods such as Muskingum-Cunge and kinematic wave. Two major reservoirs, Lake Mendocino and Lake Sonoma, are not included in the model because storage-discharge data are not available.

HEC-HMS MODEL CALIBRATION AND RESULTS

Model calibration: The calibration process is usually based on streamflow to ensure that the model operates realistically. The calibration process was used to estimate parameter values and initial conditions based on the goodness of fit between the modeled results and observed discharge for most methods, given observations of hydrometeorological conditions. Calibration was completed with a multi-step process to minimize bias. Most parameters for methods included in subbasin and reach elements can be estimated automatically within the HEC-HMS model using the optimization manager. However, observed discharge must be available for at least one element before optimization can begin. The HEC-HMS model developed for the Russian River watershed has been preliminarily calibrated due to limited data available and magnitude of the watershed. If this model is to be used in future studies then more calibration and validation may need to be done.

Hourly precipitation data for the December 12 to 16, 2002 event capable of producing significant surface runoff were used to define the hydrologic inputs. U.S. Geological Survey (USGS) flow data were used for calibration when available. The USGS has historically operated flow gaging stations in the Russian River watershed. The majority of the tributaries within the Russian River basin are not gaged. Two reservoirs' storage and discharge information were not available. A summary of historically gaged flows at six USGS gaging stations within the study area are shown in Table 1, noting again that these flows are impaired and regulated to the extent of diversions and impoundments existing during the period of record.

Table 1: Historical gage flows of Russian River		
USGS No.	**Name**	**Period of record**
11461000	Russian R NR Ukiah	1911-2002
11461500	EF Russian R NR Calpella	1942-2002
11462500	Russian R NR Hopland	1939-2002
11464000	Russian R NR Healdsburg	1939-2002
11465680	Laguna De Santa Rosa A Stony Pt Rd NR Cotati	1998-2002
11466320	Santa Rosa C A Willowside Rd	1998-2002

Figure 7 illustrates the USGS stream flow gage locations. Fifteen-minute stream flow data from these USGS gaging stations in Table 1 were provided by the U.S. Army Engineer District, San Francisco. The model was primarily calibrated to observed flows at these USGS gages.

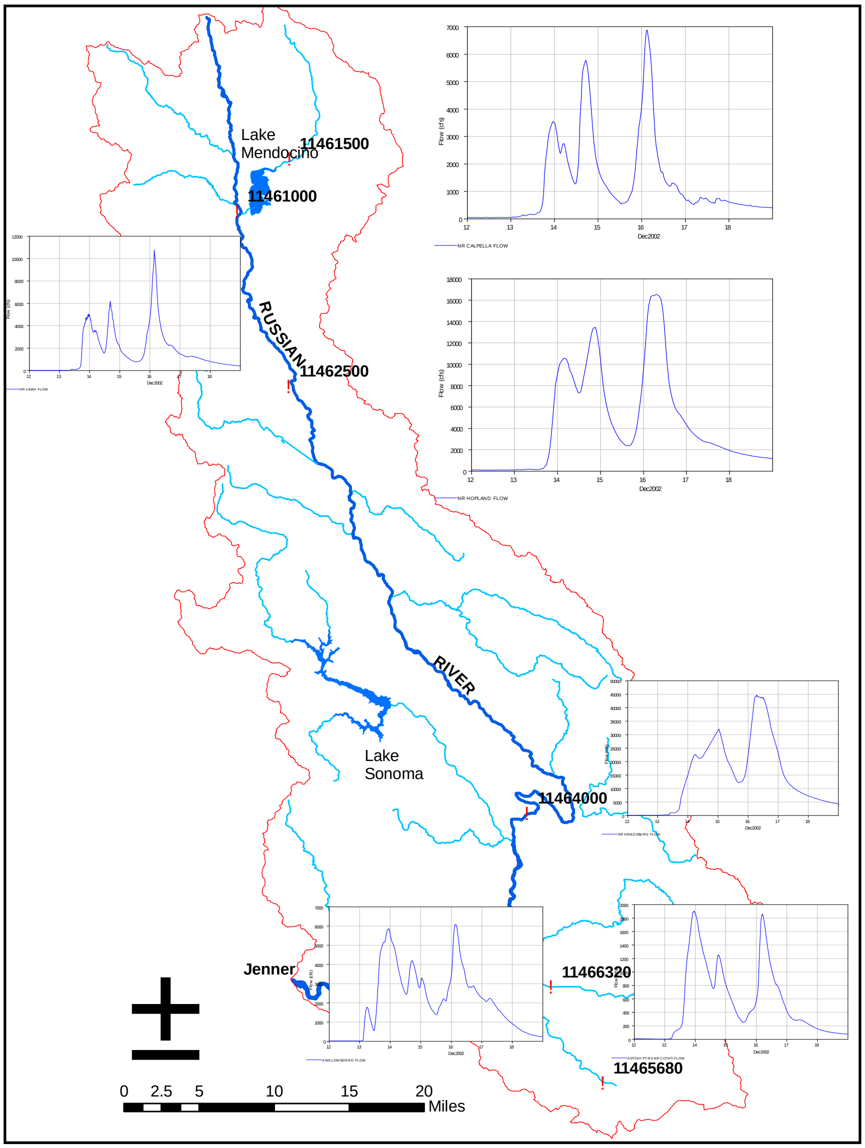


Figure 7. USGS stream flow gages.

Model Results: Computation results are viewed within the HEC-HMS basin model schematic following the execution of a run. Global and element summary tables include information on peak flow and total volume. Time-series tables and graphs are available for each element. The calibration hydrograph from the Upper Basin Model for the December 12 to 16, 2002 event for three channel reach elements is shown in Figures 8, 9, and 10.

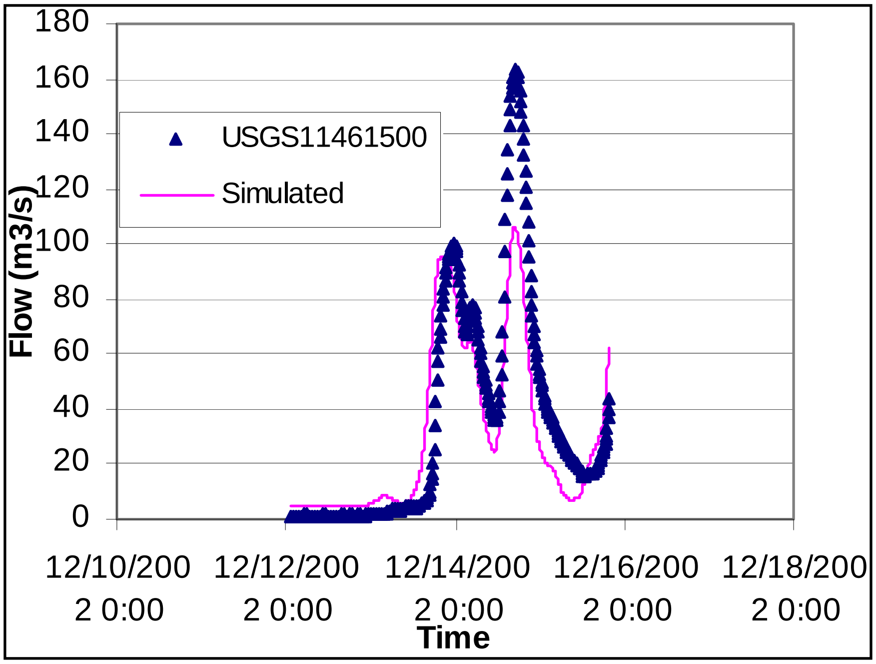


Figure 8. Comparison of observed and simulated flow discharge at USGS 11461500.

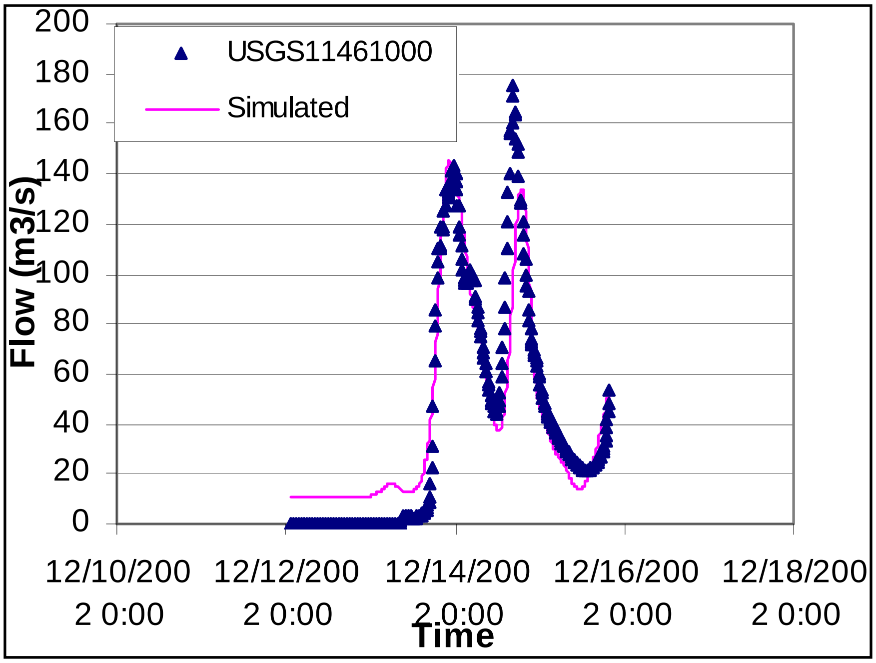


Figure 9. Comparison of observed and simulated flow discharge at USGS 11461000.

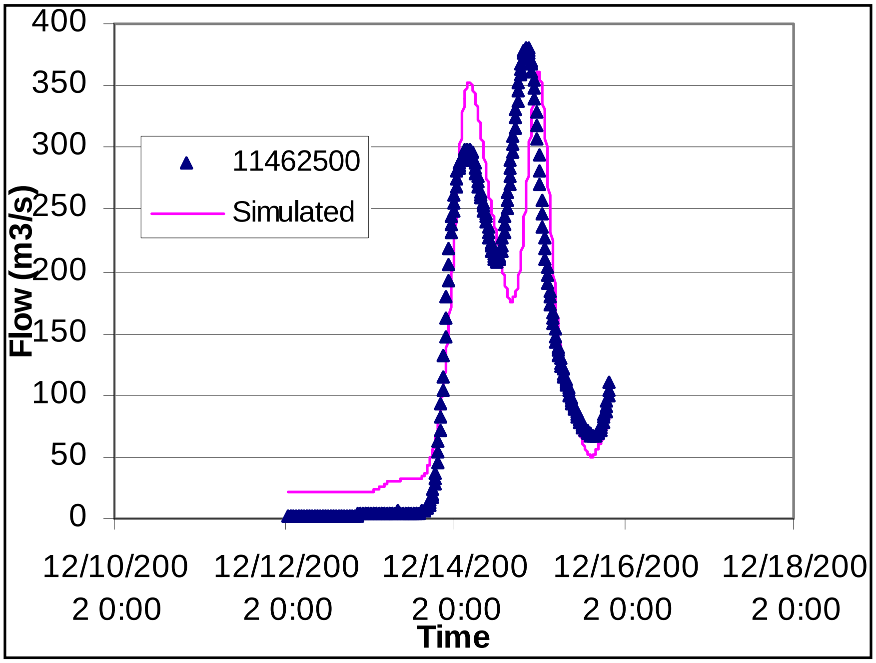


Figure 10. Comparison of observed and simulated flow discharge at USGS 11462500.

The results from the calibration process show that the modeled hydrograph matched well with the observed flows for three gages, given the data limitations discussed earlier.

The calibration hydrograph from the Lower Basin Model for the December 12 to 16, 2002 event for two channel reach elements is shown in Figures 11 and 12.

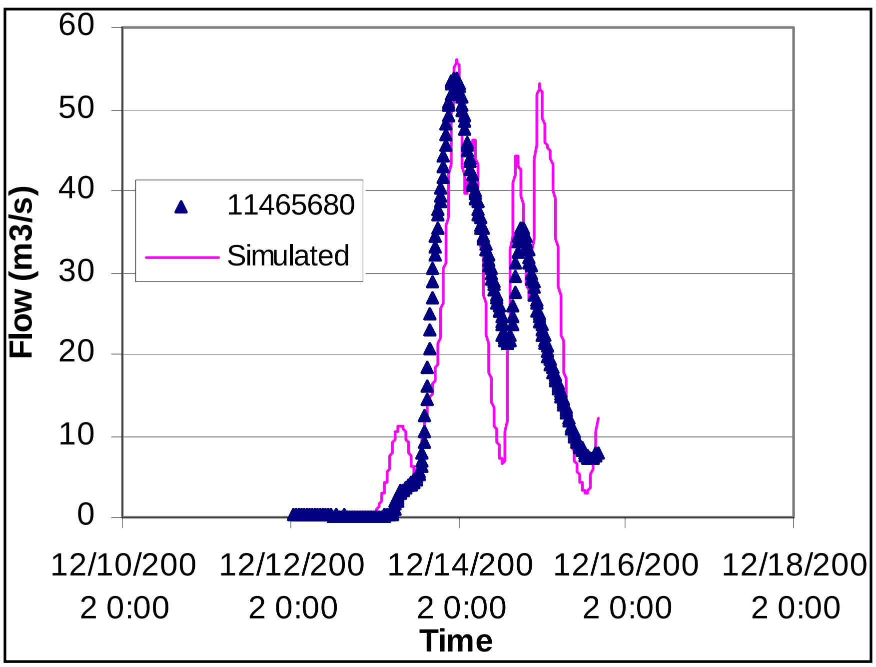


Figure 11. Comparison of observed and simulated flow discharge at USGS 11465680.

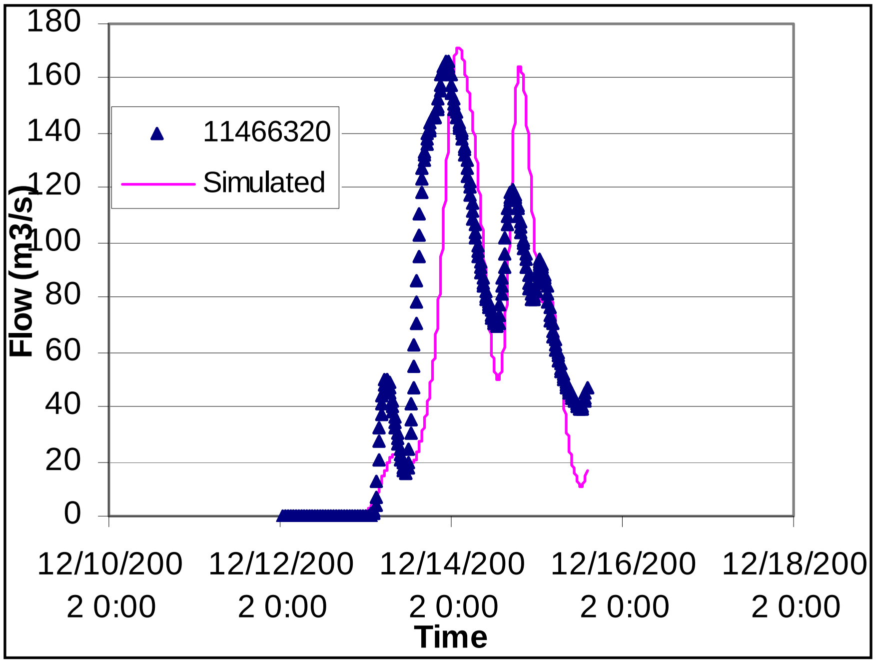


Figure 12. Comparison of observed and simulated flow discharge at USGS 11466320.

The results from these calibration plots show that the modeled hydrographs over-predict the stream flow discharge for the second storm event for both gages. The modeled discharge flow at the gaged stations greatly exceeded the observed discharge.

Based on the quality of precipitation data, limited basin and reservoir data and magnitude of the subwatershed discretization for a large-scale watershed, it will be necessary to further refine and calibrate the model before it can be used in a predictive sense.

SUMMARY: The HEC-HMS model was applied to the whole Russian River watershed. Results from the model can be used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, wetlands hydrology, and systems operation. In the development of the HEC-HMS model for this study area, available data were utilized to the greatest extent possible. The model was only partially calibrated and still needs further refinement and advancement once more data are collected. The following advancements are recommended:

- Collect refined precipitation (15 minutes) time series data.
- Collect bathymetry data for Lake Mendocino and Lake Sonoma.
- Since channel geometry data were not sufficient to simulate the hydraulics of main Russian River and major tributaries in the watershed, more data should be provided to obtain reliable simulation of water levels and flows.
- Collect water diversion, reservoir, and stream gage regulation information.

POINT OF CONTACT: For additional information, contact Dr. Billy E. Johnson, U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS (601-634-3714, *billy.e.johnson@usace.army.mil*). This technical note was written by Dr. Johnson and Dr. Zhonglong Zhang. This document should be cited as follows:

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